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TITLE: **Method and sensor for determining the local contrast of an observed scene by detection of the luminance from said scene**

The present invention relates to a method and a sensor for determining the local contrast of an observed scene by detecting the luminance of said scene using an array of CMOS photosensors.

In the optical imaging art, it is known to acquire the image of an observed scene using an array of photosensors each of which is associated with an analysis circuit forming with it what is usually referred to as a pixel. The array of pixels is preferably implemented in the form of a CMOS integrated circuit.

The photosensors of each pixel deliver a current proportional to the quantity of light that they receive from the observed scene. In practice, the average brightness of a real image may vary as a function of situation by six orders of magnitude. Consequently, the currents delivered by the photosensors may vary in the same proportions. It is therefore necessary to use adaptation circuits to adapt the currents to the levels required by the processing circuits of each pixel, which is to the detriment of the input dynamic of the system, which in practice rarely exceeds two to three orders of magnitude.

Several techniques for increasing the input dynamic are known in the art. One of them, described in a paper by S. Kavidias et al. in IEEE, Journal of Solid State Circuits, vol. 35, August 2000 entitled "A Logarithmic Response CMOS Image Sensor with On-Chip Calibration", consists in applying logarithmic compression to the current delivered by the photosensor, using low-inversion MOS transistors. The problem with this technique is that it requires matched transistors to effect logarithmic compression within the matrix of pixels. This is a considerable implementation constraint if anything like satisfactory accuracy is required.

Another technique, described for example in FR 2 605 475, in WO 98/14002 and in a paper by Y. Ni et al. in IEEE, Journal of Solid State Circuits, vol. 32, July 1997 entitled "Histogramme-Equalization-Based Adaptive Image Sensor for Real-Time Vision", consists in integrating the current delivered by the photosensor in a capacitor until a defined reference voltage is obtained across the capacitor. Each pixel of the array of pixels signals the time at which the voltage across its integrator capacitor reaches the reference value. In this case, the input dynamic is limited by the maximum integration time allowed to the system and by its intrinsic noise. This technique may be associated with methods of classifying samples using histograms. This technique is also complex and leaves something to be desired with regard to accuracy.

To overcome the problems caused by the considerable variation in

brightness, it is also known in the art to determine the local contrast of an image captured by an array of pixels. This method is of interest because, for a given element of the observed scene, the contrast has the same value whether that element is in the shade or in bright sunlight. Now, as the local contrast provides a reliable representation of the activity of each pixel, determining it eliminates the problems inherent to the prior art techniques described in the prior art documents cited above.

For a discrete unidimensional system, for example a row of pixels, the local contrast may be defined by the following expression:

$$C = 2 \bullet \frac{L_L - L_R}{L_L + L_R} \qquad (1)$$

in which C is the local contrast associated with a pixel and L_L and L_R are signals representing luminances captured by pixels to the left and to the right, respectively, of the pixel concerned. In other words, the local contrast corresponds to the local luminance gradient normalized by their average. This contrast is therefore independent of the local luminance.

The equation (1) may be applied to a captured image of a scene having a strongly illuminated area Z1 and a weakly illuminated area Z2, the reflectances of the objects present in the scene being assumed to be identical for the purposes of explanation, and the ratio of illumination of the two areas being assumed to be 5:1. This situation is illustrated by the diagram in figure 1 of the appended drawings, in which the relative luminance lr is plotted as a function of the location of pixels p1 to p21 in a row of pixels forming a portion of a unidimensional array of pixels used for experimental purposes.

Now, despite this considerable illumination difference, it is found that the contrast values calculated on the basis of equation (1) are the same for points corresponding to the two areas (pixels p1 and p11, pixels p2 and p12, pixels p3 and p13, etc.).

The definition of contrast may be extended to a bidimensional matrix of pixels M_p by distinguishing two contrast components C_x and C_y along the x and y axes of the matrix. In this case (see figure 2 of the appended drawings, which represents a portion of a matrix M_p of this kind), this means the respective luminances L_L, L_R, L_A and L_B of certain pixels p_L (left), p_R (right), p_A (above) and p_B (below) adjacent a central pixel p_C at any location in the matrix M_p (the qualifiers left, right, above and below used here have merely an explanatory meaning, the positions of the pixels in space being arbitrary).

The two components may then be written:

$$C_x = 4 \bullet \frac{L_L - L_R}{L_L + L_R + L_A + L_B}$$

$$C_y = 4 \bullet \frac{L_A - L_B}{L_L + L_R + L_A + L_B} \qquad (2)$$

In these equations also, the local contrast corresponds to the gradient of the local luminances normalized by their average.

To calculate the contrast for a given pixel in the case of the bidimensional matrix M_p, it is therefore necessary to calculate the sum of four signals representative of the luminance and to divide the difference of two signals representative of the luminance by the result of that summing operation. Complex circuits are required to effect these arithmetical operations directly in the analog domain with the required accuracy. Now, in a matrix of pixels of the kind concerned, most functions must be implemented within each individual pixel, the latter comprising the photosensor and the photocurrent integration circuit as well as the circuits for calculating the contrast associated therewith. The analog circuits needed to calculate the equations (2) above are not compatible with present day requirements for the miniaturization of matrices of pixels of the kind concerned, primarily because they are too large.

Clearly the above equations for calculating the contrast are merely indicative and may be varied without departing from the scope of the invention. The number and the position of the adjacent pixels used in the calculation are also subject to variation. In its most widely accepted sense, the term "contrast" is defined as the relative difference between the luminances of adjacent points. Moreover, and although the term "contrast" will continue to be used in the remainder of the description, it is to be understood that the invention is aimed at any calculation circuit that uses signals supplied by adjacent pixels and whose result is normalized relative to a local luminance value.

A first object of the invention is to provide a method of determining the local contrast at the level of each pixel using a circuit which, because of its low complexity, may be incorporated into the pixel without degrading the accuracy needed for determining the local contrast and without violating imposed miniaturization requirements.

The invention therefore consists in a method of determining the local contrast at the level of each pixel of an array of photosensitive pixels disposed in at least one dimension, in which method, during respective successive image capture cycles, a signal is generated that is representative of the local luminance captured by each pixel, the luminance signals being integrated values of the luminance values

captured by respective pixels,

which method is characterized in that it consists in sampling the integrated values of the signals representing the luminances captured by the pixels adjacent a pixel concerned at a time in said cycle at which the integrated value of the luminance captured by said pixel concerned becomes equal to a predetermined reference value, and determining the local contrast of said pixel concerned on the basis of the values sampled in this way.

Thanks to the above features, the means needed to obtain the value and orientation of the local contrast may be simple, a supplemental advantage of the invention being that the values obtained become independent of the level of illumination of the observed scene.

In a first embodiment of the method of the invention, said reference value is chosen as an intermediate value of the difference between a maximum white level value and a maximum black level value liable to be captured by said pixels, said intermediate value preferably being equal to half this difference.

This feature makes it possible to obtain the required values with very great accuracy, subject to a simple calculation.

It is then possible to calculate the local contrast by applying to said at least one dimension of said array the following expression:

$$C_{pn} = \frac{L_{p(n-1)} - L_{p(n+1)}}{L_{pn}}$$

in which

C_{pn} is the local contrast calculated for said cycle of a pixel of rank n in the row of the array oriented along said dimension,

L_{pn} is a signal representing the luminance captured by the pixel of rank n,

$L_{p(n-1)}$ is a signal representing the luminance captured by the preceding adjacent pixel in said row of rank n-1, and

$L_{p(n+1)}$ is a signal representing the luminance captured by the next adjacent pixel in said row of rank n+1.

Accordingly, in this first embodiment, the invention is also based on the observation that the value of the local contrast at the level of each pixel may be obtained by an approximate calculation of that value, the accuracy being entirely satisfactory in most practical situations, by making the assumption, which is also verified in most practical situations, that, for a given dimension of the array, the luminances captured each time by three pixels involved in the calculation are situated in the same plane in space. The error in the value of the local contrast obtained in this

way is in fact negligible since in a real image the low-pass filtering applied by the sensor to the observed image, whether optical or electronic, diffuses the contours, to the extent that the brightness impinging on the central pixel of the three pixels concerned is very close to the assumed theoretical value, through the simplification of the approximate calculation in accordance with the invention. The denominator of the expression defining the local contrast then contains only one value, namely that of the signal representing the luminance of the pixel p_n at which the contrast is to be determined.

According to another interesting feature of this embodiment, the signals representative of the luminance are integrated values of the luminance values captured by the respective pixels and the method further consists in sampling the integrated values of the signals representing the luminances captured by said adjacent (preceding and following) pixels at a time in said cycle at which the integrated value of the luminance captured by the pixel concerned becomes equal to a predetermined reference value, and calculating the local contrast of the pixel concerned on the basis of the values sampled in this way.

This feature has the important advantage that, for calculating the contrast, it is possible to dispense with the signal representing the luminance captured by the central pixel, without degrading the accuracy with which the contrast is determined. Because of this, calculating the contrast amounts to executing simple subtraction operations and no longer involves any division operation. The calculation circuit may then be very simple.

According to another feature of this first embodiment, the integrated values of the signals representing the luminances captured by said adjacent pixels are accumulated in respective capacitors at the time at which the integrated value of the pixel concerned reaches said reference value, said capacitors providing the values necessary for the calculation of the contrast.

The input needed by the contrast calculation circuit during each image capture cycle is therefore obtained in a particularly simple manner.

If said array takes the form of a matrix of pixels with two dimensions, the contrast calculation is effected on the basis of the following equations:

$$C_x = L_L - L_R$$

and

$$C_y = L_A - L_B$$

in which:

- C_x is the local contrast component in the x direction of the matrix,

- C_y is the local contrast component in the y direction of the matrix,
- L_L, L_R are signals representative of the luminances captured by the respective pixels adjacent the pixel concerned in the x direction,
- L_A, L_B are signals representative of the luminances captured by the respective pixels adjacent the pixel concerned in the y direction,

said expressions being used to calculate the components of the contrast vector at the level of said pixel concerned.

It further proves to be advantageous if each pair of accumulated values belonging to said x and y directions, respectively, is subjected to four-quadrant analog multiplication by a cosinusoidal signal and a sinusoidal signal of the same frequency and amplitude as said cosinusoidal signal, respectively, and in that the results of the corresponding multiplications are added to form the modulus and the phase of the local contrast vector corresponding to said pixel concerned.

This feature makes it possible to obtain the required result subject to a particularly simple implementation in each pixel of the array.

In a second embodiment of the invention, said reference value is chosen to be a maximum white level value liable to be captured by said pixels.

Although this embodiment provides only the maximum component of the contrast (cX, cY) and an orientation of the discretized contrast in octants, it proves that this kind of result may suffice in certain applications, the advantage of this being that the local contrast may be determined by logical processing of binary signals no longer necessitating any calculation operation. The necessary circuits in each pixel may then be even further simplified.

In the second embodiment of the invention, the method advantageously consists, during each of said image capture cycles, in measuring the times at which, in a group of pixels made up of the pixel concerned and its adjacent pixels, the integrated values of the luminance values captured by those pixels reach said white level value and taking as the value of the local contrast the integrated value for the pixel concerned when the first of the adjacent pixels reaches said white level value. The order in which said integrated values reach the white level value then determines the orientation of the local contrast.

The invention also provides a sensor for determining the local contrast capable of executing either of the embodiments of the method of the invention defined hereinabove.

Other features and advantages of the present invention will become apparent in the course of the following description which is given by way of example only and with reference to the appended drawings, in which:

figure 1, already described, is a diagram of the evolution of the luminance captured by a linear array of pixels as a function of their location in the array, the diagram showing an interesting property of the local contrast in this kind of linear array of pixels;

figure 2, also already described, shows part of an array in the form of a bidirectional matrix of pixels to illustrate the prior art method of calculating the local contrast;

figure 3 is a view analogous to that of figure 2 and is used to explain the basic concepts of the present invention;

figure 4 is a more detailed view of the part of the bidimensional matrix shown in figure 3;

figure 5 is a simplified diagram of a pixel forming part of the figure 4 bidimensional matrix;

figures 6 and 7 are diagrams showing the operation of the matrix represented in figure 4; and

figure 8 is a diagram of a circuit for calculating the contrast vector used in the pixel represented in figure 5;

figure 9 is a diagram of another embodiment of the invention;

figure 10 is a timing diagram showing the operation of the figure 9 embodiment of the invention;

figure 11 is a detailed diagram of one of the functional units of the figure 9 embodiment;

figure 12 is a diagram showing the operation of the figure 11 functional unit;

figure 13 is a diagram of a variant of the figure 9 embodiment; and

figure 14 is a timing diagram showing the operation of the figure 13 variant.

Figures 3 and 4 show the basic concept of a first embodiment of the invention applied to a matrix M_p of pixels forming a two-dimensional array, it being understood that this concept may be used for unidimensional arrays formed by rows of pixels.

This being so, figure 3 shows again the portion of the matrix M_p of pixels already described with reference to figure 2, but here the central pixel p_C is labelled with the luminance L_C that it may capture. According to the invention, the local contrast at the level of the central pixel p_C is calculated from the following equations:

$$C_x = \frac{L_L - L_R}{L_C}$$

$$C_y = \frac{L_A - L_B}{L_C} \qquad (3)$$

In the above equations:

- C_x is the local contrast component in the x direction of the matrix,
- C_y is the local contrast component in the y direction of the matrix,
- L_C is the signal representative of the luminance captured by the central pixel p_C,
- L_L, L_R are signals representative of the luminances captured by the pixels adjacent the central pixel p_C in the x direction,
- L_A, L_B are signals representative of the luminances captured by the pixels adjacent the central pixel p_C in the y direction.

To perform the calculation using the above equations, during each image capture cycle, the method of the invention communicates to each pixel of the matrix the signals representative of the luminances captured by the four adjacent pixels along the x and y axes. This is shown in figure 4, which is a representation to a larger scale and in greater detail of the matrix portion represented in figure 3.

Each pixel comprises a photosensor circuit ph generating a signal representing the luminance and a local contrast calculation circuit cc connected to the photosensor circuits ph of the four adjacent pixels along the x and y axes of the matrix by interpixel connections ci. Each calculation circuit cc can therefore receive the four signals representative of the luminance coming from its neighbors p_L, p_R, p_A and p_B and is adapted to perform the arithmetical operations specified in the above equations (3). Those operations being simple subtractions or divisions, the person skilled in the art will know how to design a calculation circuit for executing them with no further information. The details of the calculation circuits are therefore not described here.

Clearly figures 3 and 4 represent only a very small number of the pixels of the matrix M_p, which may comprise a large number of pixels, as is well known in the art; for example, a matrix of 64 × 64 pixels may be envisaged. As is also known in the art, each pixel has its own addressing means and payload signal transmission means based on the temporal coding method described in EP 1 150 250 in the name of the patentee of the present patent application, for example.

In the embodiment of the invention that has just been described, the calculation circuits cc must perform two subtractions and two divisions, which simplifies the calculations compared to those that had to be performed in the prior art.

Nevertheless, according to an advantageous improvement of the invention, the calculation of the local contrast components may be even further simplified and in fact reduced to two simple subtractions. An embodiment using this improvement is described next with reference to figure 5.

That figure represents a more detailed circuit of each pixel p of the matrix M_p. The photosensor circuit ph of the pixel p comprises a photodiode 1 or an appropriate equivalent photosensitive element that is disposed in series between the power supply terminals 2 and 3 with an integration capacitor 4. The node between the capacitor 4 and the photodiode 1 is connected to a semiconductor switch 5 for applying to it the signal coming from a black level terminal 6 under the control of a signal at a control terminal 7. The node in question is also connected to a follower amplifier 8 of unity gain, for example, whose output is connected to the terminal 9.

The luminance signal $V_p(t)$ is formed in the following manner.

Before exposure, the switch 5 connects the capacitor 4 to a black level voltage that is applied to the terminal 6 so that the capacitor 4 is charged to that voltage level, which represents the black level. Exposure begins with the opening of the switch 5. The photocurrent i_{ph} proportional to the luminous intensity impinging on the diode 2 is integrated in the capacitor 4. The luminance signal $V_p(t)$ may then be sampled at the terminal 9.

The terminal 9 is also connected to a first input of a comparator 10 whose other input receives a reference voltage V_{ref} that is applied to a terminal 11 of the pixel. When the voltage $V_p(t)$ reaches the value V_{ref}, the output of the comparator 10 operates four semiconductor switches 12_R, 12_L, 12_A and 12_B to which are applied respective luminance voltages $V_R(t)$, $V_L(t)$, $V_A(t)$ and $V_B(t)$ coming from adjacent pixels via the connections ci (see figure 4) and applied to corresponding terminals 13_R, 13_L, 13_A and 13_B. These voltages are sampled by means of respective sampling capacitors 14_R, 14_L, 14_A and 14_B so that they can be used at the appropriate time by a circuit 15 for calculating contrast values in which the required contrast value is preferably calculated in the form of the local contrast vector of the pixel p concerned. The corresponding data appears at a terminal 16 of the latter.

Note that the luminance signal $V_p(t)$ may be obtained from means other than those described hereinabove with reference to the photodetector circuit Ph of figure 5 provided that the output magnitude of the circuit is proportional both to the observed luminance and to the integration time. Similarly, the photosensitive element 1 may be any other component known in the art, for example a phototransistor.

To explain the operation of the other components represented in figure 5, it will be assumed that the global luminance of the observed image is constant during the integration time provided. In this case, the voltage at the terminals of the integration capacitor 4 of each pixel increases linearly as a function of time, with a slope proportional to the current of its associated diode 1, and therefore to the local luminance corresponding to the pixel concerned. It is therefore possible to write:

$$V_{ci}(t) = K \bullet L_p \bullet t \qquad (4)$$

where V_{ci} is the voltage across the capacitor 4, L_p is the local luminance, and K is a constant of proportionality depending on certain parameters such as, for example, the quantum efficiency of the technology used and the value of the integration capacitor 4. The voltage V_{ci} across the capacitor 4 is equivalent to the voltage $V_p(t)$ at the output of the unity gain follower amplifier 8.

During integration, the latter voltage $V_p(t)$ is compared continuously to the reference voltage V_{ref} applied to the terminal 11 of the pixel p. At the time t_{ref} that it becomes equal to the reference voltage V_{ref}, the output of the comparator 10 changes state and opens the semiconductor switches 12_R, 12_L, 12_A and 12_B. The respective voltages representing the instantaneous luminances of the adjacent pixels, integrated in the respective capacitors 4 thereof, are then sampled at the corresponding capacitors 14_R, 14_L, 14_A and 14_B, these voltages being respectively designated $V_R(t_{ref})$, $V_L(t_{ref})$, $V_A(t_{ref})$ and $V_B(t_{ref})$ and applied to the contrast calculation circuit 15. Note that this sampling is independent of the integration process taking place in the cells by means of the capacitors 4, that process continuing in each of the cells for as long as the inherent saturation voltage of the circuits is not reached, it being understood that the circuits must be dimensioned so that the saturation voltage is higher than the white level.

Figures 6 and 7 illustrate the operation just described. Figure 6 represents the trend of the integrated voltages (here collectively designated $V_c(t)$ on the ordinate axis) of a certain number of pixels p1 to p10 arranged on a row of the matrix of the array, assuming illumination of the latter analogous to that represented in figure 1. If the captured image is static during integration (as is assumed to be the case here), the integrated voltages $V_c(t)$ of the pixels evolve in a linear manner with time. However, in practice the integration voltages evolve only between two levels, a black level NN and a white level NB, which define an integration range assuring correct operation before the inherent saturation of the circuits is reached (see in figure 7 the straight line segment SA that represents the saturation level), the reference voltage V_{ref} being selected at around half the difference between the levels NN and NB.

Figure 7 represents the spatial profile of the integration voltages of the pixels p_1 to p_9 at different times during integration in the capacitors 4 of those pixels. The curves represented are taken at the respective times t_1, t_2, t_3, etc. (figure 6) that correspond to the profile of the voltages at the respective times that they reach the reference voltage V_{ref}. Note that in figures 6 and 7, to make the diagrams clear, not all of the pixels are represented. By way of example, there is shown the measurement of contrast at the time t_7, the contrast value resulting in this case from the difference

between the measured amplitudes in the pixels p_6 and p_8.

As a result, for any pixel of the matrix, the integration voltages necessary for calculating the local contrast are sampled when the voltage of that pixel coming from the amplifier 8 is equal to a value that is identical for the whole of the matrix. Consequently, normalizing these integration voltages amounts to dividing by a constant. Ignoring this constant (which corresponds to a gain from the electronic point of view), the sampled voltages of the pixels adjacent the pixel concerned are implicitly normalized by the voltage of the latter.

Under these conditions, the voltage differences:

$$V_{p_{cx}}(t_{ref}) = V_D(t_{ref}) - V_G(t_{ref})$$

$$V_{p_{cy}}(t_{ref}) = V_H(t_{ref}) - V_B(t_{ref}) \tag{5}$$

respectively represent, apart from the same multiplication constant, the x and y components of the contrast vector of the pixel concerned:

$$V_{p_{cx}}(t_{ref}) = k \bullet p_{cx}$$

$$V_{p_{cy}}(t_{ref}) = k \bullet p_{cy} \tag{6}$$

The voltages constitute the required result and may be processed in a manner that is known to the person skilled in the art. For example, they may be converted from analog form to digital and then processed in a digital signal processor (DSP). It may also be beneficial to preprocess the contrast vector at the level of the sensor itself to restrict the data obtained to the most pertinent information. For example, the temporal coding method described in EP 1 150 250 may be applied.

Four-quadrant multiplier means 17 (see figure 8) that form part of the calculation circuit 15 represented in figure 5 are used to calculate the contrast vectors.

The multiplier means 17 comprise two analog multipliers 18a and 18b of identical structure respectively assigned to calculations for the x and y directions in relation to any pixel p_C of the array of pixels. Each multiplier employs a function of the form:

$$I_{out} = \beta \cdot (V_1 - V_2) \cdot (V_4 - V_3) \tag{7}$$

in which:

I_{out} is the output current of the multiplier 18a or 18b appearing at a respective output 19a, 19b thereof,

- V_1 and V_2 are the voltages sampled as described with reference to figure 5, that is to say for the x direction in relation to a pixel p_C, the voltages $V_R(t_{ref})$ and $V_L(t_{ref})$, respectively, and for the y direction in relation to the same pixel, the voltages $V_A(t_{ref})$ and $V_B(t_{ref})$, respectively, and

- V_3 and V_4 are respective sinusoidal voltages $V_a \cdot \cos \varphi(t)$ and $V_b \cdot \sin \varphi(t)$ generated by sinusoidal voltage generators 20a, 21a and 20b, 21b, respectively, as shown in figure 8. Of course, the sinusoidal voltages may easily be generated by a single generator (not shown) whose diagram will be evident to the person skilled in the art.

Applying equation (7) for the multiplier 18a and using the corresponding equation (5), the resultant current I_x for the x axis becomes:

$$I_x = \beta V_A \cdot V_{p_{cx}}(t_{ref}) \cdot \cos\varphi(t) \qquad (8)$$

and similarly, for the multiplier 18b, the current I_y for the y axis becomes:

$$I_y = \beta V_A \cdot V_{p_{cy}}(t_{ref}) \cdot \sin\varphi(t) \qquad (9)$$

The outputs 19a and 19b of the multipliers 18a and 18b are connected to the inputs of an adder 22 which calculates the difference I_{tot} between the two currents I_x and I_y:

$$I_{tot} = \beta V_A \cdot V_{p_{cx}}(t_{ref}) \cdot \cos\varphi(t) + \beta V_A \cdot V_{p_{cy}}(t_{ref}) \cdot \sin\varphi(t) \qquad (10)$$

This result may be reformulated in the following manner:

$$I_{tot} = C_{p_c} \cdot \cos(\alpha_{p_c} - \varphi(t)) \qquad (11)$$

where C_{pC} and α_{pC} respectively represent the modulus and the phase of the local contrast vector of the pixel p_C, since $V_{pCx}(t_{ref})$ and $V_{pCy}(t_{ref})$ respectively represent, apart from a constant of proportionality, the components of the same vector along the x and Y axes.

The result obtained in the adder 22 is preferably then sent to a temporal coding circuit 23 as described in EP 1 150 250. That circuit supplies pulses I_{mo} and I_{ph} respectively representing in temporally coded form the modulus and the phase of the contrast vector.

The multipliers 18a and 18b are preferably as shown in figure 8, each comprising six transistors M1 to M6 connected as shown. The circuit has the advantage that the stray respective capacitances M1, M2 and M3, M4 constitute the sampling capacitors 14_R, 14_L, 14_A and 14_B of figure 5, which in this case are incorporated directly into the calculation circuit 15.

The embodiment of the invention just described with reference to figures 5 to 8 determines by calculation the norm and the orientation of the contrast vector very

accurately, which can be important in certain applications.

However, as already mentioned in the preamble, in other applications it may suffice to determine the value of the maximum component of the contrast (cX, cY) accompanied by approximate angular information as to the orientation of this vector. In that kind of application, each pixel of the sensor may be implemented even more simply than just described with reference to figures 5 to 8, since in this case the pixel may be implemented with a simple logic circuit and with no calculation circuit, which further reduces its complexity and power consumption.

The second embodiment of the sensor exploits in particular the fact that the orientation of the contrast vector can be determined on the basis of the temporal order of the information coming from the pixels adjacent the pixel concerned, in which case the orientation can be coded in binary form.

The second embodiment is described with reference to figures 9 to 14.

Figure 9 is a simplified diagram of one pixel p of the sensor, here the central pixel p_C visible in figure 3, for example. This pixel comprises a photosensor circuit ph identical to that of the pixel represented in figure 5. However, in Figure 9, the output terminal 9 of the amplifier 8 is connected to one of the inputs of a comparator 25 whose other input 26 receives a voltage V_{WHITE} representing the white level. The comparator 25 delivers at its output 27 a signal S representing the time during an image capture cycle at which the signal delivered by the amplifier 8 reaches the white level voltage V_{WHITE} (in this instance this is the signal S from the central pixel, and is therefore designated S_C).

The terminal 9 is connected to a semiconductor switch 28 controlled by the output signal of an inverting OR gate 29 with four inputs receiving the signals S_L, S_R, S_B and S_A from the comparators 25 of the respective pixels adjacent the pixel p_C. The switch 28 is also connected to a storage capacitor 30 and to the first input of another comparator 31 whose second input 32 receives a signal representing a threshold voltage $V_{th}(t)$.

The output of the comparator 31 is connected to a pulse sender 33 to which it supplies an identification signal (address) of the pixel concerned. The pulse sender 33 therefore delivers two address signals I_x and I_y that are the coordinates of the pixel concerned and a binary signal, on three bits in this example, representing the orientation of the contrast. The orientation signals I_{B0}, I_{B1} and I_{B2} are generated from binary signals B0, B1 and B2 resulting from logical processing described later of the signals S_B, S_A, S_L and S_R.

When the switch 5 is closed by the control signal applied to the terminal 7 (referred herein to as the image capture cycle command signal RST), the voltage

across the capacitor 4 is forced to take the value of the voltage V_{BLACK}. Then, when the switch 5 is opened again, the photocurrent I_{ph} caused by exposure of the sensor to the observed scene is integrated in the capacitor 4.

The output 27 of the comparator 25 is transmitted to the four adjacent pixels p_L, p_R, p_B and p_A and changes to the high state when the voltage $V_p(t)$ rises above the white level signal V_{WHITE}. The signals S_L, S_R, S_B and S_A coming from the comparators 25 of the four adjacent pixels are combined in the OR gate 29 so that the switch 28 is turned on for as long as these four signals are low. As soon as one of the four signals goes high, the capacitor 30 stores the voltage $V_p(t)$.

Figure 10 shows one example of the temporal evolution of the voltage V_p of the pixel concerned and of those V_L, V_R, V_B and V_A of its four neighbors. In this example, the contrast in the vertical direction (V_A, V_B) is greater than that in the horizontal direction (V_L, V_R). The pixel p_A is that for which the photocurrent is the highest. It is therefore the first to reach the white level V_{WHITE}. At this moment, the signal S_A at the input of the OR gate 29 of the central pixel p_C goes high with the result that the voltage V_p in this pixel is sampled in the capacitor 30. The difference between the voltage V_{WHITE} and the voltage V_p sampled at the time t_A at which the voltage V_A reaches the white level represents the maximum component of the contrast vector (C_x, C_y).

The current in the photodiode 1 of the pixel p_C (or of any other pixel of the sensor) is given by the equation:

$$I_{pC} = I_0 R_{pC} \qquad (12)$$

in which I_0 is proportional to the illumination of the observed scene and R_{pC} is the reflectance of the portion of the scene focused on the pixel p_C.

The voltage V_A reaches the white level after a time t_A given by the equation:

$$t_A = \frac{C_{30} V_{WHITE}}{I_A} = \frac{C_{30} V_{WHITE}}{I_0 R_A} \qquad (13)$$

in which C_{30} is the value of the capacitor 30 of the pixel p_C, I_A is the photocurrent in the pixel p_A, and R_A is the reflectance of the portion of the scene focused onto the pixel p_A.

The voltage V_{30} stored in the capacitor 30 of the pixel p_C is therefore:

$$V_C = \frac{I_C}{C_{30}} t_H = V_{WHITE} \frac{R_{P_C}}{R_H} \qquad (14)$$

Thus the voltage V_C is independent of the level of illumination of the sensor.

Accordingly, the second embodiment of the invention generates the maximum component of the contrast vector, rather than the norm of the contrast, by exploiting the temporal evolution of the integrated photocurrents, which avoids any

calculation in the pixels.

The pixel of the second embodiment of the invention can also provide information concerning the orientation of the contrast. To this end, as shown in figure 9, it includes an orientation determination circuit 34 of which figure 11 represents a preferred embodiment.

The orientation determination circuit 34 estimates the situation of the orientation of the contrast in eight segments of the trigonometric circle (know as octants), although the invention is not limited to this example. Depending on the required accuracy of the determination of the orientation, the person skilled in the art could modify the circuit 34 to estimate the orientation of the contrast in four segments or in more than eight segments of the trigonometric circle.

The input of the orientation determination circuit 34 is connected to the output of the inverting OR gate 29 whose output is connected to a delay circuit 35 that controls two switching transistors T1 and T2 inserted into two logic sections 34a and 34b, respectively, of the circuit 34.

Each section 34a and 34b generates a bit of the binary signal representing the orientation of the contrast. Because in this example the orientation is determined in octants, this binary signal comprises three bits B0, B1 and B2. The logic sections 34a and 34b respectively determine the values of the two more significant bits B1 and B2 as a function of the output signal of the gate 29 and the signals S_B, S_R and S_L in accordance with the following truth table:

	B2	B1
S_A	0	0
S_L	0	1
S_B	1	0
S_R	1	1

The circuit 34 also comprises a third logic circuit 34c which generates the least significant bit B0 as a function of the states B1 and B2 and the signals applied to the gate 29.

The three logic sections 34a, 34b and 34c are activated/deactivated by the command signal RST applied to respective control transistors T3, T4 and T5 provided in each section.

If the command signal RST is high, the bits B2, B1 and B0 are set to 0, the signals S_L, S_R, S_B and S_A are low, and the output of the gate 29 is high. The transistors T1 and T2 are therefore turned on. If one of the four signals S_L, S_R, S_B and S_A goes high, the bits B1 and B2 change state, if necessary. As soon as one of the inputs of the OR gate 29 is high, its output goes low. As a result of this the transistors

T1 and T2 are turned off after a delay introduced by the delay circuit 35, which prevents subsequent modification of the state of the bits B1 and B2.

The state of the bit B0 is determined by whichever of the signals S_L, S_R, S_B and S_A goes high second during the exposure cycle concerned. For example, if the bit B1 is high, the bit B0 will be set high if the signal S_B goes high before the signal S_A, indicating that the local orientation of the contrast corresponds to the octant 3 (the octant O3 in figure 12), if the bit B2 is low. On the other hand, if the bit B2 is high, it will be the octant 7 (the octant O7 in figure 12). If the bit B1 is low, for example, it will be set high if the signal S_L goes high before the signal S_R during the exposure cycle concerned.

The contrast information stored in the capacitor 30 (figure 2) is read utilizing the ramp analog/digital converter principle described in the patent EP 1 150 250. The comparator 31 compares the voltage stored in this capacitor to a reference voltage $V_{TH}(t)$ that increases with time during the exposure cycle. When the reference voltage $V_{TH}(t)$ rises above the voltage on the capacitor, a pulse coding the address of the pixel and the state of the bits B2, B1 and B0 is sent to each of the corresponding outputs Ix, Iy and I_{B2}, I_{B1} and I_{B0}. The time of appearance of the address pulses therefore codes the value of the contrast and the state of the lines I_{B2}, I_{B1}, I_{B0} codes the orientation of the contrast.

The variant represented in figure 13 refines the measured orientation of the contrast compared to that of the embodiment described with reference to figures 9 to 11. In this case, a logic circuit 36 generates a command signal if two of the signals S_L, S_R, S_B and S_A are high. This command signal operates on a switch 37 connected between the output 9 of the amplifier 8 and a capacitor 38. The voltage accumulated in the latter is transmitted to an input of a comparator 39 whose other input is at a variable reference voltage $V_{th2}(t)$ different from the reference voltage, here designated $V_{th1}(t)$, applied to the comparator 31. The inputs of an AND gate 40 are connected to respective outputs of the comparators 31 and 39 and its output is connected to the pulse sender 33.

In this variant, the voltage $V_p(t)$ is stored in the capacitor 38 when, during the cycle, a second neighbor of the pixel concerned reaches the white level, emitting its signal S_L, S_R, S_B or S_A. Under these conditions, the voltages stored in the capacitors 30 and 38 represent the two components of the contrast, the state of the bits B2 and B1 distinguishing between the X and Y components.

Taking the figure 10 situation by way of example, the capacitor 30 stores the voltage $V_p(t)$ when the signal S_A goes high and the capacitor 38 stores that voltage when the signal S_R goes high. When they have been read, these two voltage values

may be combined to refine the measured orientation.

They are then read in two stages, as shown in figure 14. In a first stage, the ramp voltage $V_{th1}(t)$ reads the voltages stored in the capacitors 30 of the pixels. This ramp starts from the voltage V_{BLACK} and terminates at a voltage V_{cmin} that is either chosen as a function of the application or adjusted in a loop to optimize the quantity of the read information, limiting the transmission of contrast to pixels for which the maximum component of the contrast is greater than V_{WHITE} - V_{cmin}. In a second phase, the voltage $V_{th1}(t)$ is maintained at the voltage V_{cmin}. At the same time, the voltage $V_{th2}(t)$ changes between V_{BLACK} and V_{WHITE}. A pixel sends a measurement pulse when the comparator 39 changes state only if the output of the comparator 31 is high (AND gate 40).